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Targeting Minimum Heat Transfer Area for Heat Recovery on Total Sites

Stanislav Boldyryev*,[a], Petar Sabev Varbanov[b], Andreja Nemet[b], Petro Kapustenko[a], Jiří Jaromír Klemeš[b]

[a]AO "SODRUGESTVO – T" Company, per. Krasnoznamenny, 2 off. 19, 61002 Kharkiv, Ukraine
[b]Centre for Process Integration and Intensification – CPI[2], Research Institute of Chemical and Process Engineering-MÜKKI, Faculty of Information Technology, University of Pannonia, Egyetem u. 10, H-8200 Veszprém, Hungary
stas.boldyryev@gmail.com

This paper upgrades the Total Site integration methodology, when accounting for a trade-off between capital and heat recovery by selection of optimal temperature levels for intermediate utilities and therefore, decrease capital cost. Heat transfer area for recuperation in Total Site is a two-fold problem and it depends on the Sink Profile on one side and on the Source Profile on another. The resulting temperature of intermediate utility is a result of a trade-off since the heat transfer area on Source side is decreasing, when temperature of IM is decreasing, however increased on Sink side. In the opposite higher intermediate utility temperature leads to higher area on the Source side and lower on Sink side. The temperature of each intermediate utility may be varied between specified lower and upper bounds subject to serving the Sink and Source Profiles.

1. Introduction

Ahmad et al. (1990) showed and approved a connection between the heat recovery and heat transfer area, which is connected to capital cost for Heat Exchangers Networks of individual processes. Townsend and Linnhoff (1984) presented methodology for calculation of heat transfer area for heat recovery. Mostly it focuses also on individual processes and steady state Pinch Analysis as shown by Wan Alwi et al. (2012). A total cost targeting method for heat exchanger network synthesis is presented by Serna-González and Ponce-Ortega (2011). It combines existing targeting methods for the grass-roots design problem with a new method for simultaneous targeting of network area and pumping power cost (i.e., optimum pressure drops of streams). Nemet et al. (2013) presented an optimisation methodology for a Heat Exchanger Network design over its entire lifespan. Consideration of fluctuating energy prices is essential for achieving an optimal HEN design. The objective function presented a trade-off between investment and operating costs.

However, all these methodologies presented before are developed for a single process integration and capital cost evaluation. A higher level of integration is obtained at Total Site level, where various processes are connected through a central utility system. The Total Site integration has a large potential for energy saving through the heat recovery via the utility system (Klemeš et al, 2010) and for potential reduction of environmental footprints (Čuček, et al, 2012). At this level the heat recovery system makes even more considerable input to capital cost than at process level as two heat transfer stages are needed due to the intermediate carrier – the utility. Nemet et al. (2012) developed a general methodology for heat transfer area evaluation and capital cost targeting of Total Site heat recovery systems. The approach is based on the a priori specification of the intermediate utility levels. It assumed constant temperature of the intermediate utility during the heat recovery. However, a proper selection of the intermediate utility temperature has a significant influence on heat transfer area and consequently also on the capital cost. The present paper develops further the methodology for minimisation of heat transfer area in Total Site heat recovery system. Therefore, it can reduce the capital cost for Total Site heat integration.

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2. Methodology

The methodology for estimating heat transfer area includes the selection of number of intermediate utilities available and determination of intermediate utility temperatures. The Total Site Sink and Source Profiles should be plotted together on the T-H diagram applying individual ΔT_{min} specifications for heat exchange between process streams in order to present the streams with their real temperatures as shown by Nemet et al. (2012).

2.1 Enthalpy intervals definition

This procedure estimates heat transfer area for different temperature of intermediate utilities and selects the minimum of heat transfer area. The Total Site Sink and Source profiles should be constructed together on the T-H diagram and shifted to make a heat recovery as was shown by Nemet et al. (2012). However, different intermediate utilities are proposed for each enthalpy interval as shown on Figure 1. Heat recovery should be preferably performed within each enthalpy intervals separately. For each enthalpy interval the intermediate utility level has to be properly selected, in order to correspond to minimum heat transfer area of enthalpy interval. Figure 1 shows the heat recovery field divided to enthalpy intervals. This figure is based on a previous work by Ahmad et al. (1990) who analysed the heat transfer for Process Integration level and process – utility level. However, Nemet et al. (2012) developed a methodology for estimation of heat transfer area for only one pre-defined intermediate utility for Total Site heat recovery. In this procedure the minimal area requirement for Total Site heat recovery is determined as a sum of minimum heat transfer area of each enthalpy interval..

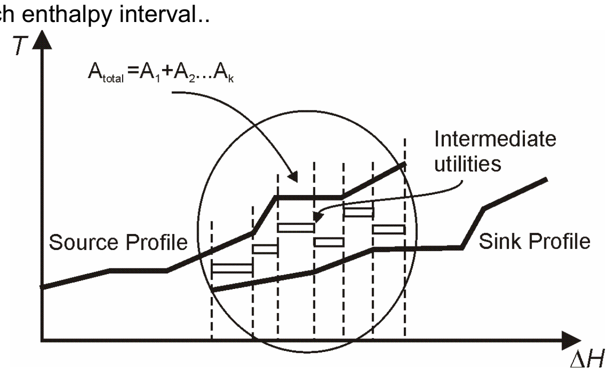

Figure 1: Total Site heat recovery region divided on enthalpy intervals

2.2 Selection of intermediate utilities levels

Modification of the approach, which was presented by Ahmad et al. (1990), allows estimation of two side heat transfer area by using of intermediate utility. Heat transfer area of each temperature interval consists from two areas of source-intermediate and intermediate-sink heat exchange. Mean logarithmic temperature difference is changed for each level of intermediate utility. Temperature of intermediate utility is changed from low to upper bounds which are limited by minimal temperature difference on source-intermediate ΔT_1 and intermediate-sink sides ΔT_2 (Figure 2). Equation for heat transfer area estimation presented by Ahmad et al. (1990) should be modified in order to estimate heat transfer area in enthalpy interval for different level of intermediate utility - Eq (1). However, the same IM is assumed for each temperature level of intermediate stream.

$$A_{EI} = \frac{1}{\Delta T_{LM}^{H}}\left(\sum_{i=1}^{n}\frac{Q_i}{h_i} + \frac{Q_{IM}}{h_{IM}^{H}}\right) + \frac{1}{\Delta T_{LM}^{C}}\left(\sum_{j=1}^{m}\frac{Q_j}{h_j} + \frac{Q_{IM}}{h_{IM}^{C}}\right) \quad (1)$$

The first term of Eq (1) presents the heat transfer area required to exchange heat between hot streams (*i*) and intermediate utility (*IM*), while the second term stands for required heat transfer area to transfer heat from intermediate utility (*IM*) to cold streams (*j*) in a certain enthalpy interval (*EI*).
The minimal heat transfer area is selected within each enthalpy interval:

$$A_{min,EI} = \min(A_{1,EI}, A_{1,EI}, ..., A_{1,l}) \quad (2)$$

The sum of minimal heat transfer area of each enthalpy interval forms the total minimal area of heat recovery and shows the optimal temperature for intermediate utilities:

$$A_{min\,Rec} = \sum_{p=1}^{k} A_{min,EI} \tag{3}$$

The methodology has been shown on a case study. Case study presented the calculation of total heat transfer area of Total Site.

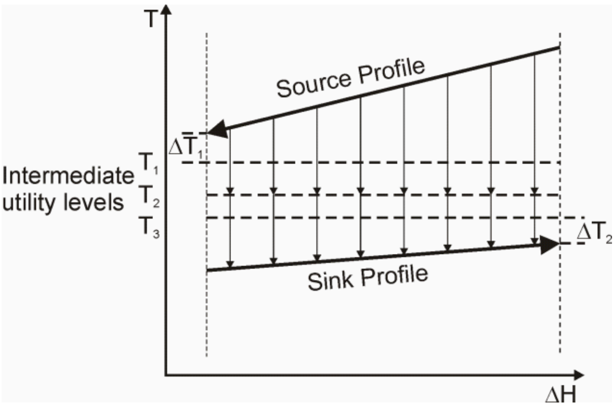

Figure 2: Selection of temperature of intermediate utility (developed after Ahmad et al., 1990)

3. Case study

3.1 Data extraction

The case study uses the stream data of three individual processes. These processes were integrated by pinch methodology and streams are accounted for when plotting Total Site Profile described by Nemet et al. (2012). There are six process streams with specific phase and thermo-physical properties. These streams were collected to the Table 1.

Table 1: Stream data of Total Site analysis

№	Stream	Type	TS, °C	TT, °C	CP, MW/°C	ΔH, MW	h, MW/(m^2·°C)
1	A1 Liquid	hot	100	40	0.05	3.00	0.00080
2	B2 Gas	hot	180	130	0.03	1.50	0.00011
3	C2 Liquid	hot	80	40	0.02	0.80	0.00100
4	A3 Liquid	cold	80	120	0.03	1.20	0.00070
5	B4 Liquid	cold	100	140	0.04	1.60	0.00090
6	C3 Gas	cold	150	240	0.02	1.80	0.00015

Total Site Profiles were built applying data in Table 1 and shifted to create heat recovery area (Figure 3). In order to perform heat recovery an intermediate utility is needed - see (3a) and (3b) in Figure 3. The overlapping part representing the heat recovery was distributed by enthalpy intervals. The temperature range of intermediate utility is limited by Sink and Source profile temperatures e.g. for (3a) it is 105 and 125 °C, for (3b) it is 115 and 145 °C (Figure 4). Site hot utility is a middle pressure steam with temperature 250 °C, cold utility is cooling water with temperature range from 20 to 30 °C. Film heat transfer coefficients for hot and cold utilities are 0.001 and 0.0079 MW/(m^2·°C). Table 2 represents the initial data of intermediate utilities for selected enthalpy intervals.

Table 2: Data of intermediate utilities

Enthalpy interval	ΔH, MW	T_{IM1}, °C	T_{IM2}, °C	ΔT_{min}, °C	h_{IM1}, MW/(m^2·°C)	h_{IM2}, MW/(m^2·°C)
#1	0.6	105	125	5	0.0081	0.0056
#2	0.9	115	145	2	0.0080	0.0054

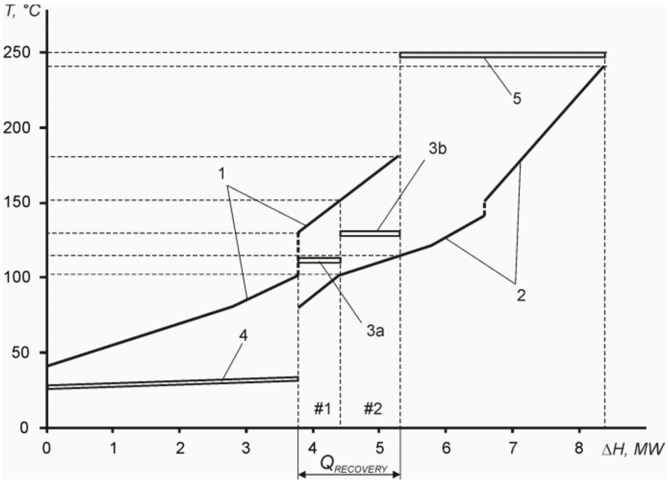

Figure 3: Case study Total Site Profiles. (1) – Source Profile; (2) – Sink Profile; (3) – intermediate utilities; (3a) – intermediate utility of enthalpy interval #1; (3b) – intermediate utility of enthalpy interval #2; (4) – cold utility (cooling water); (5) – hot utility (middle pressure steam); #1, #2 – enthalpy intervals

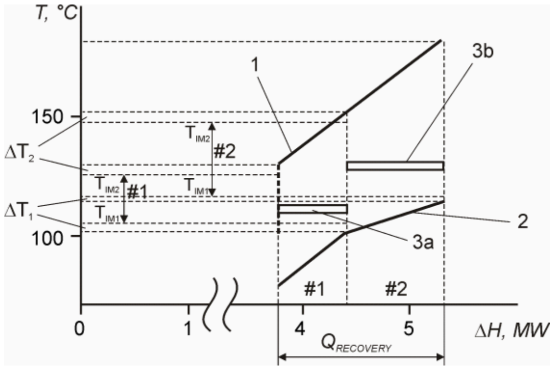

Figure 4: Case study – Heat Recovery of Total Site. 1 – Source Profile; 2 – Sink Profile; 3 – Intermediate Utilities; #1, 2 – Enthalpy Intervals

3.2 Optimal temperature selection

Heat transfer area for each enthalpy interval is calculated by Eq (1). Temperature of intermediate utility is changed from low bound (T_{IM1}) to upper bound (T_{IM2}). T_{IM1} for enthalpy interval #1 it is 105 °C for enthalpy interval #2 it is 115 °C and T_{IM2} is 125 °C for interval #1 and 145 °C for interval #2 (see Figure 4). The results of heat transfer area calculations are presented in Figure 5. Minimal heat transfer area is obtained for temperatures 105 °C and 125 °C of intermediate utilities for the first and second enthalpy intervals. Appropriate placement of intermediate utility is shown in Figure 3 and Figure 4.

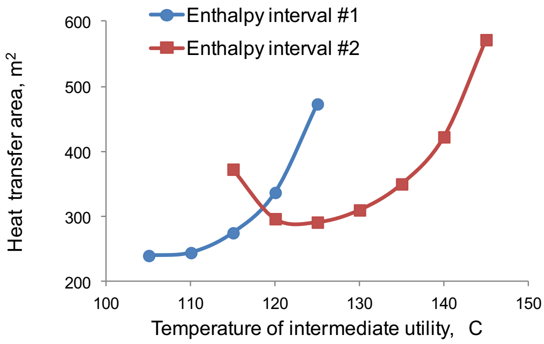

Figure 5: Heat transfer area for enthalpy intervals

4. Results and discussion

A methodology for estimating minimum heat transfer area with a pre-defined rate of heat recovery on Total Site level with use of intermediate utility has been developed. The implementation of it can reduce heat transfer area and consequently capital cost of heat exchangers on the Total Site. Minimal heat transfer area in the first enthalpy interval is at 105 °C equal 240.08 m^2, while in the second enthalpy interval is at 125 °C equal 291.48 m^2. Those two observations lead to conclusion that the lowest area required for the heat recovery for this case study can be 531.56 m^2. The heat transfer areas for heat exchange between process and cold or hot utility on Total Site are independent from intermediate utility levels. 221.00 m^2 area is required for heat transfer from hot streams to cold utility and 338.51 m^2 for heating cold streams applying hot utility. The total heat transfer area of Total Site can be minimised down to 1,091.06 m^2 applying presented methodology. However, it can be as high as 1,604.88 m^2 without considering proper intermediate utility temperature. This indicates that proper selection of the temperature level of the intermediate utility the area can be decrease in this case study up to 32.02 %.

This considerable decrease in heat transfer area and with it the investments can be utilised for retrofit as well as to save the operation cost for utility reduction at the designing stage of Total Site. This methodology has some limitations connected with technological issues. They include changes of film heat transfer coefficient for different temperatures of intermediate utility and its estimation. Different levels of intermediate utility can require different types of heat exchangers that lead to changing (in some case increasing) of capital cost. The flow rate of intermediate utility in enthalpy interval can be small and transportation of this stream to another process may not be profitable. It needs the additional analysis. Even considering those issues the extended methodology still offers a step ahead to estimation of the capital cost for Total Site heat recovery. There are also the issues of data reconciliation which should be considered (Manenti et al, 2011). The further development should deal with the problems listed. Number of enthalpy intervals should be investigated as well accounting for heat exchange placement and installation cost. Additional enthalpy interval needs installation and repiping cost. This point is also connected with pipe length between the Total Site processes. Pipe length has considerable contribution to capital cost and the running cost (pressure drop, pumping) for Total Site heat recovery system and should be optimised as well. Some of those issues have been recently investigated by Chew et al (2013). Some additional information can be also found in Klemeš (2013). It has been also considered to add this methodology into Total Site Sensitivity Table (TSST) and potentially connect it with Total Site Problem Table Algorithm (TS-PTA) – see Liew et al (2013).

5. Conclusions

This case study shows considerable potential for energy saving on Total Site level by heat recovery improvement with use of intermediate utilities as well as capital cost reduction via minimum heat transfer area definition. The amount heat recovered is 1.5 MW, for which minimum heat transfer area is determined to be 531.56 m^2. It is obtained when temperatures of intermediate utility are 105 °C and 125 °C. Total minimum heat transfer area for this case study on Total Site is 1,091.06 m^2, which is 32.02 % less then without applying the developed methodology, where the total area for heat exchange can be up to 1,604.88 m^2. Proposed extended methodology indicates potential of capital cost reduction for heat exchangers network design on Total Site level. It allows making a general recommendation for selection of heat exchangers design and selection and decreases the investment. The methodology may be used for estimation of investments for Total Site integration.

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Nomenclature

$Q_{RECOVERY}$ – heat recovery, MW;
T – temperature, °C;
TS – supply temperature, °C;
TT – target temperature, °C;
T_{IM} – temperature of intermediate utility, °C;
T_{IM1} – low temperature of intermediate utility, °C;

T_{IM2} – high temperature of intermediate utility, °C;
h_{IM1} – film heat transfer coefficient of intermediate utility on source side, W/(m^2 °C)
h_{IM2} – film heat transfer coefficient of intermediate utility on sink side, W/(m^2 °C)
CP – heat capacity flowrate, MW/°C;
ΔH – enthalpy, MW;
A_{total} – heat transfer area, m^2;
A_{minEI} – minimum heat transfer area of enthalpy interval, m^2;
A_{minRec} – minimum heat transfer area of heat recovery, m^2;
A_{EI} – total heat transfer area of enthalpy interval, m^2;
ΔT_{min} – minimal temperature difference between two process streams, °C
ΔT_1 – minimal temperature difference for source side, °C
ΔT_2 – minimal temperature difference for sink side, °C
ΔT_{LM}^{H} – logarithmic temperature difference for source side, °C
ΔT_{LM}^{C} – logarithmic temperature difference for sink side, °C
ΔT_{LM} – logarithmic temperature difference, °C
Q_i – heat of i hot stream, MW;
Q_j – heat of j cold stream, MW;
Q_{IM} – heat of intermediate utility, MW;
h_i – film heat transfer coefficient of i process stream, W/(m^2 °C);
h_j – film heat transfer coefficient of j process stream, W/(m^2 °C);
h_{IM}^{C} – film heat transfer coefficient of intermediate utility, W/(m^2 °C);
n – number of hot streams in enthalpy interval;
m – number of cold streams in enthalpy interval;
k – number of enthalpy intervals.

References

Ahmad S., Linnhoff B., Smith R., 1990, Cost optimum heat exchanger networks – 2. Targets and design for detailed capital cost models, Computers & Chemical Engineering 14(7), 751-767.

Chew, K.H., Klemeš, J.J., Wan Alwi, S.R., Abdul Manan, Z. ,2013, Industrial implementation issues of Total Site Heat Integration, Applied Thermal Engineering, doi: 10.1016/j.applthermaleng.2013.03.014

Čuček L., Varbanov P. S., Klemeš J. J. and Kravanja Z., (2012), Potential of total site process integration for balancing and decreasing the key environmental footprints, Chemical Engineering Transactions, 29, 61-66

Dhole V. R., Linnhoff B., 1993, Total site targets for fuel, co-generation, emissions, and cooling, Computers & Chemical Engineering 17, S101-S109.

Nemet A., Klemeš J. J., Kravanja Z., 2013, Optimising entire lifetime economy of heat exchanger networks, Energy, doi.org/10.1016/j.energy.2013.02.046.

Nemet A., Varbanov P.S., Kapustenko P., Boldyryev S., Klemeš J.J., 2012. Capital Cost Targeting of Total Site Heat Recovery, Chemical Engineering Transactions 29, 1447-1452.

Klemeš J.J., Ed. 2013, Process Integration Handbook, Woodhead Publishing, Cambridge, UK, ISBN-13: 978 0 85709 593 0

Klemeš J.J., Varbanov P.S., 2012, Heat integration including heat exchangers, combined heat and power, heat pumps, separation processes and process control, Applied Thermal Engineering 43, 1–6.

Klemeš J., Friedler F., Bulatov I., Varbanov, P. 2010, Sustainability in the process industry – Integration and optimization. New York: McGraw-Hill., USA, 362 p.

Liew, P.Y., Wan Alwi, S.R., Varbanov, P.S., Manan, Z.A., Klemeš, J.J., 2013, Centralised utility system planning for a Total Site Heat Integration network, Computers and Chemical Engineering, doi: 10.1016/j.compchemeng.2013.02.007

Manenti F., Grottoli M.G., Pierucci S, 2011, Online Data Reconciliation with Poor Redundancy Systems, Ind. Eng. Chem. Res., 2011, 50 (24), 14105–14114

Serna-González M., Ponce-Ortega J.M., 2011, Total cost target for heat exchanger networks considering simultaneously pumping power and area effects, Applied Thermal Engineering 31(11–12) 1964-1975.

Townsend D.W., Linnhoff B., 1984, Surface area targets for heat exchanger networks, IChemE 11th Annual Research Meeting, Bath, UK, Lecture 7a.

Wan Alwi S.R., Manan Z.A., Nam S.K., 2012, A New Method To Determine The Optimum Heat Exchanger Network Approach Temperature, Computer Aided Chemical Engineering 31, 190-194.